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Agroecosystem management effects on soil carbon and nitrogen

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ABSTRACT

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The cumulative effects of long-term (1980–1990) tillage and crop rotation management on soil organic C and N concentrations and potential mineralization were determined. Tillage systems studied were conventional moldboard plow tillage and conservation tillage, with various crop rotations including: continuous soybean (*Glycine max* L.)–wheat (*Triticum aestivum* L.) cover (SW); continuous corn (*Zea mays* L.)–wheat cover (CW); and corn–wheat cover–soybean–wheat cover (CWSW). Surface soil (0–5, 5–10, and 10–20 cm depth increments) organic C and N concentrations and potential mineralization were determined for all tillage/rotation combinations in October 1990. After 10 years, surface soil organic C and N concentrations were 67% and 66% higher, respectively, under conservation tillage than plow tillage to a depth of 10 cm. Potential C and N mineralization followed a pattern similar to organic C and N distribution. However, differences in substrate quality below 10 cm indicated that conservation tillage promoted N immobilization. Crop rotation had less effect than tillage on soil organic C and N amounts and potential mineralization. Rotations with higher frequency of corn (CW and CWSW) had higher organic C and N concentrations and C mineralization than SW; crop rotation had no effect on potential N mineralization. Tillage system apparently influenced soil organic matter concentrations and mineralization via crop residue incorporation rather than any effects owing to concentration differences at the soil surface, while the effect of crop rotation was related to amount of crop residues added between 1980 and 1990.

INTRODUCTION

Tillage strongly influences the quantity and quality (potentially mineralizable C and N) of soil organic matter. Soils under reduced tillage regimes tend to accumulate crop residues on the surface, resulting in wetter, cooler and

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more compact soils with greater concentrations of organic C and N than those under conventional tillage (Blevins et al., 1977; Lamb et al., 1985; Havlin et al., 1990). Greater amounts of surface soil organic C and N with reduced tillage in comparison with conventional tillage systems have been attributed to slower, less oxidative microbial metabolism under reduced tillage (Doran, 1980). Conventional tillage systems, when compared with reduced tillage systems, have been shown to decrease potentially mineralizable C and N (Woods and Schuman, 1988) and the soil's ability to immobilize and conserve mineral N (Follett and Schimel, 1989). Greater potentially mineralizable N under reduced tillage than conventional tillage in the upper 7.5 cm of soil has been associated with a larger microbial biomass (Doran, 1980). However, Doran (1980) found the reverse at depths below 15 cm. Differences in potential mineralizable N were attributed to differences in crop residue incorporation between tillage systems. These studies suggest that tillage plays a key role in soil N availability.

Crop rotations, owing to differences in amount and chemical composition of crop residues, may affect soil organic matter concentration and potential mineralization. Surface soil organic C and N concentrations were greater in continuous sorghum (*Sorghum bicolor* L. Moench) and sorghum–soybean rotations than continuous soybean rotations, and were linearly related to amount of crop residue addition (Havlin et al., 1990). Wagger et al. (1985) reported greater net N mineralization from sorghum than from wheat residues in Kansas. After only 3.5 years, greater potential C and N mineralization were found in soils under wheat–corn–millet (*Panicum miliaceum* L.)–fallow than wheat–fallow rotations (Wood et al., 1990). Differences were attributed to greater input of crop residues under the wheat–corn–millet–fallow rotation. Wood et al. (1990) also found greater C and N turnover under wheat–corn–millet–fallow than wheat–fallow rotations, indicating differences in soil organic matter quality among rotations.

The chemical, physical and biological benefits of maintaining or increasing soil organic matter concentrations in agroecosystems are numerous (Tisdale et al., 1985). Unfortunately, erosion and enhanced decomposition promote rapid losses of soil organic matter in soils brought under cultivation in moist, subtropical climates, such as that of the southeastern US (Langdale et al., 1985). Retarded losses or even gains in soil organic matter and nutrient supplying capability (mineralization), however, may be realized with appropriate selection of tillage and crop-rotation system. Yet, little information exists, especially on soils of the southeastern US, concerning the cumulative interactive effects of tillage and crop rotation on soil organic matter concentrations and mineralization. The current study was conducted to examine the effects of long-term (10 years) tillage and crop rotation management on soil C and N concentrations and potential mineralization in a moist, subtropical climate.

MATERIALS AND METHODS

Soil organic C, organic N and potential C and N mineralization were measured on soil samples collected in October 1990 from a long-term tillage/rotation study at Crossville, AL (34°18′ N, 86°01′ W). The soil at the study site is a Hartsells fine sandy loam (fine-loamy, siliceous, thermic Typic Hapludults). The study was established in 1980, and prior to initiation of the study the site had been used for row crop production for more than 50 years. The climate at the study site is classified as subtropical with no dry season; the mean annual rainfall is 1325 mm, and the mean annual temperature is 16°C (Shaw, 1982).

The experimental design was a tillage (2) by rotation (3) factorial with four replications arranged as a split plot with tillage treatments as main plots. Rotations included continuous soybean–wheat cover (SW), continuous corn–wheat cover (CW) and corn–wheat cover–soybean–wheat cover (CWSW). Wheat cover was added to the rotation schemes owing to its widespread use as an erosion control measure and as a winter forage for livestock in the southeastern US. Wheat cover in these rotations was killed or plowed under, depending on the tillage system employed, prior to grain fill. Tillage treatments included conventional plow tillage (moldboard plowing, to 20 cm, the wheat cover in the spring followed by incorporation of herbicide with a disk), and conservation tillage (planting in killed wheat residue with a double disk opener planter). In both plow tillage and conservation tillage, a once-over, shallow (to 10 cm) disking operation was used for wheat cover seedbed preparation each fall. This shallow disking operation resulted in minimal incorporation of summer crop (corn or soybean) residues.

Before wheat cover planting in the fall of each year, 56 kg N ha^{-1} was applied to all plots and incorporated with the shallow disking operation. Corn received 56 kg N ha^{-1} at planting and an additional 168 kg N ha^{-1} 2–3 weeks after emergence each year of the study. All N fertilizers were broadcast applied as NH_4NO_3. No additional N fertilizer was applied to soybean plots. Lime and P and K fertilizers were broadcast applied in the fall before wheat planting according to Auburn University Soil Test recommendations. Weed control in corn consisted of atrazine [6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] applied pre-emergence at a rate of 2.2 kg a.i. ha^{-1} followed by [2,4-DB(2,4-dichlorophenoxy)butyric acid] applied post-emergence at 0.6 kg a.i. ha^{-1}. Linuron [N′-(3,4-dichlorophenyl)-N-methoxy-N-methyl-urea] at 0.7 kg a.i. ha^{-1} and 2,4-DB at 0.2 kg a.i. ha^{-1} were tank-mixed and applied post-directed to soybean for weed control. On plow-tillage plots planted to soybean, trifluralin [2,6-dinitro-N,N-dipropyl-4-(trifluoromethyl)benzenamine] at 0.6 kg a.i. ha^{-1} was applied preplant incorporated for grass control. Additional weed control in plow-tillage plots was achieved by cultivation as needed. Row spacing was 92 cm, 69 cm and 18 cm for corn, soybean and wheat, respectively.

Soil in each plot was sampled on 31 October 1990, collecting 0–5, 5–10 and 10–20 cm depth increments. Thirty soil cores (18 mm diameter) were collected per plot and composited within each depth. Surface plant residues were not included in soil samples.

Soil samples were refrigerated at 5°C until incubation. These field moist soils were sieved to pass at 2 mm, and 25 g (dry weight basis) samples were weighed into plastic containers. Deionized water was added to bring samples to −12 kPa. Samples were placed in 1-l jars containing 20 ml of water to maintain humidity, and a vial containing 8 ml of 1 mol NaOH to trap respired CO_2 (Anderson, 1982). Jars were incubated at 25°C for 30 days.

Soil organic C and N, and inorganic N (NO_3–N plus NO_2–N, and NH_4–N) were measured before incubations were initiated. Soil inorganic N and respired CO_2–C were measured upon termination of the 30-day incubation. Soil organic C was determined with a LECO CHN-600 analyzer (LECO, Augusta, GA). Soil organic N was determined by Kjeldahl procedures (Bremner and Mulvaney, 1982). Inorganic N was extracted with 2 mol KCl, and analyzed with a Wescan ammonia analyzer. Carbon dioxide in NaOH traps (Wescan Instruments, Deerfield, IL) was determined by titrating excess base with 1 mol HCl in the presence of $BaCl_2$ (Anderson, 1982).

Soil potential N mineralization was calculated as the difference between final and initial contents of inorganic N for each 30-day incubation. Potential C mineralization was calculated as the difference between the incubation base trap and the mean of four blanks. Carbon turnover and relative N mineralization were calculated as the fraction of C or N mineralized from organic C or N respectively (Burke et al., 1989).

Soybean and corn grain were removed from all plots each year with a plot combine, while plant residues remained. Over the 10-year study period, corn grain yields ranged from 3.7 to 8.9 Mg ha^{-1}, while soybean grain yields ranged from 1.1 to 2.2 Mg ha^{-1}. A complete evaluation of tillage and rotation effects on grain yields in this study are reported elsewhere (Edwards et al., 1988). The amounts of crop residues returned to the various cropping systems were estimated from grain yields and averaged for the years 1980–1990. Estimates of corn residue weight were obtained by multiplying corn grain production for each plot by a residue weight:grain weight ratio of 1.0 (Larson et al., 1978). Similarly, estimates of soybean residue weight were obtained by multiplying soybean grain production for each plot by a residue weight:grain weight ratio of 1.5 (Larson et al., 1978). Wheat cover residue was determined yearly by clipping 7.4 m^2 areas in the center of each plot 1 week prior to corn or soybean planting.

Analyses of variance were performed using the SAS Package (SAS Institute, 1988), testing for all main effects and their interactions. The data were analyzed as a split–split plot with tillage as main plots, crop rotation as subplots, and soil depth as sub–subplots. All statistical tests were made at the $\alpha=0.05$ level. Appropriate standard error of the mean difference and t' functions were used for calculations of pair comparisons (LSD) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Tillage effects

Cumulative effects of tillage were apparent in organic matter concentrations of the surface soil (Tables 1 and 2). Soil organic C concentration was 77% and 61% higher in conservation tillage than plow tillage in the 0–5 and 5–10 cm depth increments, respectively, after 10 years (Table 2). No significant differences in organic C concentration existed below 10 cm, as shown by the significant tillage×soil depth interaction (Tables 1 and 2). Soil organic N followed a pattern similar to organic C; soil organic N concentrations were 84% and 48% greater under conservation tillage than plow tillage in the 0–5 and 5–10 cm soil depths, respectively, and no significant differences were observed below 10 cm. Depth distribution differences for soil organic C and N between tillage systems were also evident in the 0–20 cm soil layer; soil organic C and N were stratified under conservation tillage while a more even distribution existed under plow tillage (Table 2).

Although changes in organic C and N concentrations owing to tillage system were expected, the large magnitude of difference was surprising. In a similar study, Hargrove et al. (1982), also working in the southeastern US, found no differences in soil organic matter among tillage systems. They hypothesized that soil organic matter could not accumulate in the southeastern US to the extent that is has in other localities (Blevins et al., 1977), because the mild climate enhances crop residue decomposition. Our results indicate that for arable soils in moist subtropical climates, higher levels of soil organic C and N can be maintained with conservation tillage than with plow-tillage systems.

Differences in soil organic C and N concentrations between tillage systems influenced potential C and N mineralization (Table 3). Respiration (C mineralization) under conservation tillage was approximately twice that under plow tillage in the 0–5 cm layer. No differences in respiration between tillage systems existed below 5 cm, which probably resulted from mixing of crop residues to plow depth in plow tillage. Like soil organic C concentration, respiration was highly stratified with depth under conservation tillage, while smaller differences among depths were observed under plow tillage, an indication of crop residue mixing under plow tillage. Potential N mineralization, as influenced by tillage, followed a pattern similar to respiration (Table 3). Potential N mineralization was 92% greater under conservation tillage than

TABLE 1

Analysis of variance F probabilities for soil organic C and N, C mineralized, C turnover, N mineralized, relative N mineralization and C:N mineralized

Variance source	Organic C	Organic N	C mineralization	C turnover	N mineralization	Relative N mineralization	C:N mineralized
	$P>F$						
Tillage (T)	<0.001	0.005	0.013	0.231	0.216	0.406	0.112
Rotation (R)	0.136	0.096	0.032	0.047	0.276	0.188	0.311
Soil Depth (D)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.008
T×R	0.450	0.050	0.470	0.146	0.114	0.030	0.308
T×D	<0.001	<0.001	<0.001	0.002	<0.001	0.232	0.027
R×D	<0.001	0.451	0.024	0.062	0.884	0.743	0.310
T×R×D	0.101	0.290	0.430	0.327	0.785	0.155	0.346

TABLE 2

Soil organic C and N in October 1990 as affected by 10 years of tillage management at Crossville, AL

Soil Depth (cm)	Organic C ($g\ kg^{-1}$)			Organic N ($g\ kg^{-1}$)		
	PT[1]	CT	Mean	PT	CT	Mean
0–5	6.0	10.6	8.3	0.49	0.90	0.70
5–10	5.9	9.5	7.7	0.50	0.74	0.62
10–20	5.6	5.7	5.7	0.47	0.52	0.50
Mean	5.8	8.6	7.2	0.49	0.72	0.60
$LSD_{0.05}$[2]		1.5			0.10	
$LSD_{0.05}$[3]		0.3			0.09	
$LSD_{0.05}$[4]		1.0			0.14	
$LSD_{0.05}$[5]		0.4			0.12	

[1]PT, conventional plow tillage, CT, conservation tillage.
[2]LSD for comparison of two tillage means (averaged over all crop rotation treatments and soil depths).
[3]LSD for comparison of two soil depth means (averaged over all tillage and crop rotation treatments).
[4]LSD for comparison of two tillage means (averaged over all crop rotation treatments) at the same or different soil depths.
[5]LSD for comparison of two soil depth means at the same level of tillage (averaged over all crop rotation treatments).

plow tillage in the 0–5 cm soil layer. Below 5 cm, potential N mineralization did not differ between tillage systems. Potential N mineralization was more stratified under conservation tillage than plow tillage, and lowest values were found in the 10–20 cm depth.

Carbon turnover was greater under conservation tillage than plow tillage in the 0–5 cm soil layer (Table 3), suggesting differences in soil organic matter quality (Schimel et al., 1985). Below 5 cm, C turnover was greater under plow tillage than conservation tillage, even though soils under conservation tillage had greater (5–10 cm) or equal (10–20 cm) soil organic C concentrations (Table 2). Apparently, soil organic matter under conservation tillage below 5 cm was more resistant to decomposition than that under plow tillage, which again may be explained by residue incorporation under plow tillage. Relative N mineralization decreased with soil depth, but the tillage×soil depth interaction was not significant (Table 1). Therefore, greater potential N mineralization under conservation tillage than plow tillage for the 0–5 cm layer was probably owing to the larger organic N pool under conservation tillage (Table 2), rather than differences in N substrate quality. Equal potential N mineralization (Table 3) and relative N mineralization (data not shown) between tillage systems in the 5–10 cm layer suggest differences in N substrate quality, because soil under conservation tillage had greater amounts of organic N at that depth than did those under plow tillage (Table 2). Below 10

TABLE 3

Soil potential C and N mineralization, C turnover and C:N mineralized in October 1990 as affected by 10 years of tillage management at Crossville, AL

Soil depth (cm)	C mineralization ($mg\ kg^{-1}$)			C turnover (%)			N mineralization ($mg\ kg^{-1}$)			C:N mineralized ($g\ kg^{-1}$)		
	PT[1]	CT	Mean	PT	CT	Mean	PT	CT	Mean	PT	CT	Mean
0–5	211	434	323	3.6	4.2	3.9	13	25	19	18	32	25
5–10	150	195	173	2.6	2.1	2.3	9	10	9	19	21	20
10–20	130	90	109	2.4	1.7	2.0	6	3	5	22	67	45
Mean	163	240	201	2.8	2.6	2.7	9	13	11	20	40	30
$LSD_{0.05}$[2]		14			NS[6]			NS			NS	
$LSD_{0.05}$[3]		30			0.4			3			16	
$LSD_{0.05}$[4]		97			0.2			7			39	
$LSD_{0.05}$[5]		42			0.5			4			22	

[1]PT, conventional plow tillage; CT, conservation tillage.
[2]LSD for comparison of two tillage means (averaged over all crop rotation treatments and soil depths).
[3]LSD for comparison of two soil depth means (averaged over all tillage and crop rotation treatments).
[4]LSD for comparison of two tillage means (averaged over all crop rotation treatments) at the same or different soil depths.
[5]LSD for comparison of two soil depth means at the same level of tillage (averaged over all crop rotation treatments).
[6]NS, not significant at $\alpha=0.05$.

cm, potential N mineralization, relative N mineralization and amount of organic N were not affected by tillage system (Tables 1–3).

The ratio of C:N mineralized is an index of labile substrate availability (Burke et al., 1989). Large proportions of available C relative to N can result in N immobilization (Nadelhoffer et al., 1991). The higher C:N mineralized ratio under conservation tillage than plow tillage in the 10–20 cm soil layer (Table 3) indicates a N limitation for heterotrophic microbes under conservation tillage. These data suggest that soils under long-term conservation tillage management may have greater potential for N immobilization in soil layers below the immediate surface than those under plow tillage.

Crop residue incorporation probably accounts for the differences in surface soil C and N concentrations, mineralization and turnover between tillage treatments. The plow tillage system mixed crop residues into the soil to 20 cm and allowed accelerated decomposition (Doran, 1980). In contrast, crop residues remained on the soil surface in the conservation tillage system, perhaps slowing decomposition rates. Higher soil organic C and N concentrations in 5–10 cm layers of conservation tillage than plow tillage may have resulted from the once-over, shallow disking operation at wheat planting each fall. The magnitude of differences in soil organic C and N concentrations

TABLE 4

Average residue addition and percent contribution of residue types between 1980 and 1990 as affected by tillage and rotation at Crossville, AL

Tillage[1]	Crop rotation[2]	Average annual residue addition[3] (Mg ha^{-1})	Soybean average addition[4] (Mg ha^{-1})	Soybean percent contribution[5] (%)	Corn average addition[4] (Mg ha^{-1})	Corn percent contribution[5] (%)	Wheat cover average addition[6] (Mg ha^{-1})	Wheat cover percent contribution[5] (%)
PT	SW	11.22	2.16	19.2			9.06	80.8
	CW	14.17			5.69	40.2	8.48	59.8
	CWSW	14.35	2.59	9.0	6.50	22.7	9.80	68.2
	Mean	13.24	2.37	14.2	6.10	31.4	9.11	69.6
CT	SW	12.74	2.59	20.3			10.14	79.7
	CW	14.23			5.51	38.7	8.72	61.3
	CWSW	14.15	3.16	11.2	6.36	22.5	9.39	66.3
	Mean	13.70	2.89	15.7	5.94	30.6	9.41	69.1
Rotation mean	SW	11.97	2.37	19.8			9.60	80.2
	CW	14.20			5.60	39.5	8.60	60.5
	CWSW	14.25	2.88	10.1	6.43	22.6	9.60	67.3
	Mean	13.47	2.62	15.0	6.02	31.0	9.27	69.3

ANOVA	$P>F$	$LSD_{0.05}$	$P>F$	$LSD_{0.05}$	$P>F$	$LSD_{0.05}$	$P>F$	$LSD_{0.05}$	$P>F$	$LSD_{0.05}$	$P>F$	$LSD_{0.05}$	$P>F$	$LSD_{0.05}$
Tillage (T)	0.033	–[7]	0.041	-	0.094	NS	0.510	NS	0.506	NS	0.204	NS	0.615	NS
Rotation (R)	0.004	1.13	0.003	-	<0.001	-	0.032	-	<0.001	-	0.058	NS	<0.001	1.8
T×R	0.215	NS	0.318	NS	0.446	NS	0.942	NS	0.246	NS	0.212	NS	0.138	NS

[1]PT, conventional moldboard plow tillage; CT, conservation tillage.
[2]SW, continuous soybean; CW, continuous corn; CWSW, alternate corn–soybean; wheat (W) was used as a winter cover crop in all systems.
[3]Average annual residue addition is (1980–1990 wheat plus soybean and/or corn residues) 10 years^{-1}.
[4]Soybean or corn average addition is (1980–1990 residue amount) per number of years in crop (10 years for SW or CW and 5 years for CWSW).
[5]Soybean, corn or wheat cover percent contribution is ((1980–1990 residue amount/10)/(total average annual residue addition))×100.
[6]Wheat cover average addition is (1980–1990 wheat residue) 10 years^{-1}.
[7]Only two means; no LSD value given.

among tillage systems to a depth of 10 cm suggests that the light disking operation in conservation tillage did not accelerate decomposition to the extent of plowing in the plow tillage system. The depth distribution data further support this reasoning. In 0–5 cm soil layers, a combination of C and N pool sizes and quality appeared to control potential C and N mineralization differences between tillage systems. Below 5 cm, potential C and N mineralization was probably controlled by substrate quality. Our results are in agreement with previous studies in drier climates (Woods and Schuman, 1988; Wood et al., 1990) that demonstrate the sensitivity of soil organic matter quality (potential mineralization and turnover) to changes in tillage practices. Those studies showed that reduced tillage promotes soil organic matter quality in agroecosystems as indicated by rates of soil C and N mineralization, turnover and ratios of C:N mineralized.

Another factor that may have influenced soil organic matter levels and quality was the slightly greater return of crop residues under conservation tillage than plow tillage (Table 4). However, the 4% greater average annual residue addition under conservation tillage than plow tillage could not account for the large differences in soil organic matter concentrations and potential mineralization between tillage systems. Only soybean average residue additions were increased by conservation tillage, but their percent contribution to the average annual residue addition was small and did not vary with tillage system (Table 4). Assuming a soil bulk density of 1.3 g cm^{-3} and a plant residue C concentration of 400 g kg^{-1}, increased organic C (conservation tillage over plow tillage) in the 0–10 cm soil layer was approximately three times the additional residue C added in conservation tillage. Similarly, assuming a plant residue N concentration of 10 g kg^{-1}, increased organic N (conservation tillage over plot tillage) in the 0–10 cm layer was approximately nine times the additional residue N added in conservation tillage. Therefore, greater soil organic C and N under conservation tillage were related to less decomposition of soil organic C and N originating from crop residues when compared with plow tillage, rather than differences in residue amounts between tillage systems.

Crop rotation effects

Crop rotation had less impact on surface soil organic C and N concentrations than did tillage system (Tables 1 and 5). Soil organic C concentration was greater under CW than SW rotations in the 0–5 cm soil layer (Table 5), as shown by the significant rotation×soil depth interaction (Table 1). Although not significant ($P=0.096$), soil organic N concentration tended to be greater under CW and CWSW than SW rotations across all soil depths (Table 5). A significant tillage×rotation interaction was present regarding soil organic N concentration (Table 1). Soil organic N concentration was greater

TABLE 5

Soil organic C and N in October 1990 as affected by 10 years of crop rotation management at Crossville, AL

Soil depth (cm)	Organic C ($g\ kg^{-1}$)			Organic N ($g\ kg^{-1}$)		
	SW[1]	CW	CWSW	SW	CW	CWSW
0–5	7.5	9.1	8.3	0.64	0.71	0.74
5–10	7.2	8.4	7.6	0.61	0.60	0.65
10–20	5.8	6.1	5.1	0.46	0.58	0.45
Mean	6.8	7.8	7.0	0.57	0.63	0.61
$LSD_{0.05}$[2]		NS[5]			NS	
$LSD_{0.05}$[3]		1.3			NS	
$LSD_{0.05}$[4]		0.5			NS	

[1]SW, continuous soybean; CW, continuous corn; CWSW, alternate corn–soybean; wheat (W) was used as a winter cover crop in all crop rotations.
[2]LSD for comparison of the crop rotation means (averaged over all tillage treatments and soil depths).
[3]LSD for comparison of two crop rotation means (averaged over all tillage treatments) at the same or different soil depths.
[4]LSD for comparison of two soil depth means at the same level of crop rotation (averaged over all tillage treatments).
[5]NS, not significant at $\alpha=0.05$.

TABLE 6

Soil organic C and N in October 1990 as affected by 10 years of tillage and crop rotation management at Crossville, AL

Crop[1] rotation	Organic C ($g\ kg^{-1}$)		Organic N ($g\ kg^{-1}$)	
	PT[2]	CT	PT	CT
SW	5.7	8.0	0.49	0.65
CW	6.1	9.6	0.48	0.78
CWSW	5.6	8.4	0.50	0.73
$LSD_{0.05}$[3]	NS[5]		0.01	
$LSD_{0.05}$[4]	NS		0.08	

[1]SW, continuous soybean; CW, continuous corn; CWSW, alternate corn–soybean; wheat (W) was used as a winter cover crop in all crop rotations.
[2]PT, conventional plow tillage; CT, conservation tillage.
[3]LSD for comparison of two tillage means (averaged over all soil depths) at the same or different levels of crop rotation.
[4]LSD for comparison of two crop rotation means (averaged over all soil depths) at the same or different levels of tillage.
[5]NS, not significant at $\alpha=0.05$.

TABLE 7

Soil potential C mineralization and C turnover in October 1990 as affected by 10 years of crop rotation management at Crossville, AL

Soil depth (cm)	C mineralization (mg kg^{-1})			C turnover (%)		
	SW[1]	CW	CWSW	SW	CW	CWSW
0–5	262	335	372	3.4	3.6	4.6
5–10	159	184	174	2.2	2.4	2.4
10–20	114	109	104	2.0	2.0	2.1
Mean	178	209	217	2.6	2.6	3.0
$LSD_{0.05}$[2]		29			0.4	
$LSD_{0.05}$[3]		51			NS	
$LSD_{0.05}$[4]		52			NS	

[1]SW, continuous soybean; CW, continuous corn; CWSW, alternate corn–soybean; wheat (W) was used as a winter cover crop in all crop rotations.
[2]LSD for comparison of two crop rotation means (averaged over all tillage treatments and soil depths).
[3]LSD for comparison of two crop rotation means (averaged over all tillage treatments) at the same or different soil depths.
[4]LSD for comparison of two soil depth means at the same level of crop rotation (averaged over all tillage treatments).

TABLE 8

Relative N mineralization in October 1990 as affected by 10 years of tillage and crop rotation management at Crossville, AL

Crop[1] rotation	Relative N mineralization (%)		
	PT[2]		CT
SW	1.8		2.3
CW	2.1		1.3
CWSW	2.0		1.4
$LSD_{0.05}$[3]		0.7	
$LSD_{0.05}$[4]		0.7	

[1]SW, continuous soybean; CW, continuous corn; CWSW, alternate corn–soybean; wheat (W) was used as a winter cover crop in all crop rotations.
[2]PT, conventional plow tillage; CT, conservation tillage.
[3]LSD for comparison of two tillage means (averaged over all soil depths) at the same or different levels of crop rotation.
[4]LSD for comparison of two crop rotation means (averaged over all soil depths) at the same or different levels of tillage.

under the CW and CWSW than the SW rotation under conservation tillage across all soil depths (Table 6). No significant differences in soil organic N concentration among rotations were found under plow tillage. These results indicate that conservation tillage systems, and to a lesser extent crop rotations including corn, promote higher concentrations of organic C and N than do plow tillage systems and rotations including soybean. This agrees with recent work done in Kansas and Ohio (Dick et al., 1986a, b; Havlin et al., 1990).

The influence of crop rotation on potential C mineralization followed a similar pattern to total C concentrations (Tables 1, 5 and 7). Within crop rotations, potential C mineralization decreased with depth, except in the SW rotation where no differences were observed between 5–10 and 10–20 cm depths (Table 7). Lower potential C mineralization was found under SW than rotations including corn in 0–5 cm soil layers, and highest values were found under CWSW. Greater potential C mineralization in 0–5 cm layers under CWSW was linked to higher C substrate quality, as indicated by greater C turnover (Table 7). However, greater potential C mineralization under CW than SW in 0–5 cm layers appeared to be controlled by soil organic C concentration, because C turnover did not differ between CW and SW. These results suggest that soil organic matter originating from diverse mixtures of crop residues (such as corn and soybean in the CWSW system) that vary in quality may promote the highest levels of soil microbial activity. Similar observations were reported by Wood et al. (1990). Crop rotation had no effect on potential N mineralization (Table 1). Relative N mineralization was greater under plow tillage than conservation tillage in the CW rotation (Table 8), suggesting a N limitation for heterotrophic microbes under conservation tillage for CW. Lower relative N mineralization under CW and CWSW than SW under conservation tillage (Table 8) also indicates that N was limiting for decomposer activity where corn was grown. Ratios of C:N mineralized did not vary with crop rotation (Table 1).

The effects of crop rotation on surface soil organic matter concentration and mineralization, unlike the effects of tillage, were owing to the amount and probably the quality (C:N ratio) of crop residues added to the soil between 1980 and 1990. Less crop residue was added to soils in SW than CW or CWSW rotations owing to the low average addition of soybean residues (Table 4). Lower amounts and possibly higher quality (N content) of soybean residues were probably responsible for lower surface soil C and N concentrations and C mineralization under SW. Unfortunately, residue quality data were not collected in this study. However, soybean residues generally have higher N concentrations than corn residues, and, thus, soybean residues decompose at a more rapid rate than corn residues (Parr and Papendick, 1978). Therefore, soybean residues are less likely to accumulate as soil organic matter. Corn produced approximately twice the amount of crop residue as did soybean, and percent contribution of corn or soybean residues in CWSW were approximately half that in SW or CW, respectively. However, soybean and corn average residue addition were greater in rotation than monoculture, indicating higher long-term biomass productivity with rotations than monocultures. This is in agreement with grain yield data collected at this site (Edwards et al., 1988), and a recent study in Georgia (Moorman and Dowler, 1991). Long-term residue biomass productivity with CWSW equalled that in CW, resulting in equal surface soil organic C and N.

Wheat cover was common to and comprised most of the residue addition in all rotations (Table 4). What cover residue addition did not vary with crop rotation. Thus, wheat cover residue addition probably had minimal influence on differences in soil organic matter amounts and mineralization, unless wheat residue differed in quality between rotations (data not available). Although wheat cover addition did not vary with rotation, wheat percent contribution to the total residue addition increased as the frequency of soybean in rotations increased, and was the result of lower residue biomass productivity of soybean.

SUMMARY

Tillage, and to a lesser extent crop rotation, had a marked impact on soil organic C and N concentrations, potential mineralization, and turnover. The conservation tillage system had higher soil organic C and N concentrations to a depth of 10 cm than did plow tillage owing to positioning of crop residues in relation to the soil surface over the 10-year study period. Greater total organic C and N in conservation tillage than plow tillage was manifested in higher potential C and N mineralization. Below 10 cm, however, heterotrophic microbes in conservation tillage soils appeared more N-limited than those in plow tillage soils, suggesting a greater potential for N immobilization with conservation tillage. Crop rotations affected the concentration of soil organic matter, and it appeared that corn promotes greater stability of soil organic matter than does soybean. With respect to plant residue biomass production that supplied organic material for soil organic matter transformations, it appeared that conservation tillage and rotation of corn and soybean was superior to plow tillage and monocultures of either crop. Our results indicate that management provides options for controlling soil organic matter levels and microbial transformations that supply nutrients to plants in moist, subtropical climates.

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